Multi-constrained QoS Multicast Routing Optimization

Naouel Ben Ali, Miklos Molnar, Abdelfattah Belghith

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Multi-constrained QoS Multicast Routing Optimization

Naouel Ben Ali, Miklós Molnár and Abdelfattah Belghith

N°6500

Avril 2008

Systèmes communicants

Rapport de recherche

ISSN 0249-6399

Multi-constrained QoS Multicast Routing Optimization

Naouel Ben Ali*, Miklós Molnár †and Abdelfattah Belghith ‡

Systèmes communicants
Projet AT-REN

Rapport de recherche n ° 6500 — Avril 2008 — 48 pages

Abstract: In the future Internet, multimedia applications will be strongly present. When a group of users is concerned by the same traffic flow, the multicast communication can decrease considerably the network bandwidth utilization. The major part of this kind of multicast communication needs quality of service (QoS) specification. Often, the QoS is given as a set of QoS criteria and the computation of feasible or optimal routes corresponds to a multi-constrained optimization. Finding the multicast graph respecting the defined QoS requirements and minimizing network resources is a NP-complete optimization task. Exhaustive search algorithms are not supported in real networks. Greedy algorithms was proposed to find good multicast sub-graphs. The local decisions of greedy algorithms can lead to solutions which can be ameliorated. To improve greedy algorithm solution, we propose, first, ICRA algorithm which is an enhanced version of the well known Mamcra algorithm but is also limited. As Meta-heuristics are good candidates to find better solutions using a controlled execution time, we propose, secondly, Taboo-QMR algorithm which is a Taboo Search based algorithm to reduce the multicast sub-graph computed by the first step of the algorithm Mamcra. Simulations of all approaches are run based on random graphs and show that the application of Taboo-QMR algorithm presents a tangible enhancement in almost 32 per cent of the cases.

Key-words: Network, multicast routing, QoS, multi-constrained optimization, taboo search

(Résumé : tsvp)

Ce travail a été réalisé dans le cadre d'une collaboration entre l'Irisa de Rennes et l'ENSI de Tunis financée par la coopération INRIA - STIC - Universités Tunisiennes.

* naouel.benali@ensi.rnu.tn
† miklos.molnar@irisa.fr
‡ abdelfattah.belghith@ensi.rnu.tn

Unité de recherche INRIA Rennes
IRISA, Campus universitaire de Beaulieu, 35042 RENNES Cedex (France)
Téléphone : 02 99 84 71 00 - International : +33 2 99 84 71 00
Télécopie : 02 99 84 71 71 - International : +33 2 99 84 71 71

Optimisation du routage multicast avec plusieurs contraintes de Qualité de service

Résumé : Les applications multimédias distribuées déployées dans l'Internet actuel ont fait naître un besoin urgent en infrastructure de communication offrant une qualité de service garantie et prévisible. Générallement, la qualité de service est exprimée sous formes de plusieurs critères à satisfaire et le calcul d'une structure de routage satisfaisant plusieurs critères correspond à un problème d'optimisation difficile. D'ailleurs, le calcul du graphe multicast satisfaisant les besoins requis par les applications et minimisant l'utilisation des ressources est un problème NP-complet. Comme les algorithmes de recherche exhaustive ne sont pas envisageables dans le cas de déploiement dans un réseau de communication, des algorithmes heuristiques et souvent gloutons peuvent être adoptés pour trouver la solution à un tel problème. Sauf que, les décisions locales et irrévocables prises par ce genre d'algorithme peuvent mener à des solutions qu'on peut améliorer. Pour améliorer, Mamcra, l'unique approche gloutonne existant dans la littérature, nous proposons tout d'abord ICRA, qui est un algorithme incrémental qui corrige certains points faibles de Mamcra mais reste toujours limité. Puis, nous proposons, l'adoption de Taboo-QMR, qui est basée sur une approche métaheuristique, la recherche tabou. Taboo-QMR permet d'éviter les minima locaux dans lesquels sont piégés les algorithmes itératifs tels que ICRA et Mamcra et permet de trouver une meilleure solution la plupart des cas.

Mots-clé : Réseaux, routage multicast, QoS, optimisation multicritère, recherche "tabou"

1 Introduction

Recently, the Internet has shown a tremendous growth. Emergent multicast applications like audio/video conferencing, video on demand, IP-telephony, etc. usually have Quality Of Service (QoS) requirements, which include bandwidth, bounded delay, jitter and loss rate. Several IP multicasting techniques have been proposed to support point-to-multipoint communications by sharing link resources leading to a reduction in network resource consumption. All these techniques are based on IP multicast routing protocols which use shortest path tree algorithm based on one single metric, typically delay or hop count. Multicast applications today needs to optimize more than one metric that's why multi-constrained QoS routing should be applied. QoS routing is a routing scheme under which paths for flows are attributes by taking into account flow requirements and are based on some knowledge of resource availability in the network. Multicast routing deployed in the Internet aims to use resources efficiently. In a point to multipoint session, p destinations will receive the same information. Sending p times over each shortest path to each individual multicast member is inefficient. Sending single packets through the shared links and duplicating them if it is necessary is more efficient. When we consider a single metric, multicast source routing can be achieved by forwarding packets over the shortest path tree for example. When the overall cost of the tree must be minimized, the problem must be tackled differently. Determining the minimal cost multicast tree for a multicast group corresponds to the Steiner Tree problem which is shown to be NP-complete [11]. An additional dimension to the multicast routing problem is to construct trees or sub-graphs that will satisfy multiple QoS requirements. Routing problem (in the rest of the paper, QoS routing refers to multi-constrained QoS Routing) even in the unicast case is known to be NP-complete problem and has been extensively studied by the research community. [20] gives an overview of the main proposed QoS routing algorithms which try to find a path between a source and a destination node that satisfies a set of constraints. For the multicast case, a number of QoS routing algorithms based on single, dual and multiple metrics have been proposed. Single metric QoS multicast routing algorithms have been proposed for cost [26, 2, 27] and for delay [6, 13]. Dual metric based routing algorithms have been formulated for the following combinations: cost-delay [18, 25, 10] and delay-jitter [24, 27]. For the general case of the multi-constrained multicast routing problem which involves multiple QoS metrics, only one algorithm has been proposed due to the complexity nature of this problem. Multicast Adaptive Multiple Constraints Routing Algorithm (Mamcra) [17] attempts to find multiple QoS constrained paths to the multicast members in an efficient but not always optimal manner. The main idea of Mamcra is to compute multi-constrained shortest paths from the source node to each destination using a unicast QoS routing algorithm, Samcra [22]. The set of obtained paths is then optimized to determine a multicast sub-graph that uses as few links from the first paths set as possible. Mamcra proposes a greedy heuristic approach to solve this second problem. The quality of the approximation isn't proved and the shortcoming of the proposed greedy algorithm can be improved. This paper deals with multiple constrained QoS multicast routing problem which constitutes one of the most interesting problems of multi-objective optimization in network field. In this paper, we will focus, essentially, on optimizing the set of shortest paths to solve the multiple constrained QoS multicast routing problem. The set of paths can be obtained by Samcra or any multiple constrained QoS unicast routing algorithm. Considering the drawbacks of Mamcra's greedy algorithm, we propose ICRA, an improvement version of the greedy algorithm and Taboo-QMR a global optimization based on a meta-heuristic approach, namely on the taboo search, Taboo-QMR provides a solution which can be close to the optimal solution.

This paper is organized as follows. Section 2 specifies the multiple constraint problems for unicast and multicast QoS routing and provide an overview of most proposed approaches to treat these problems. Section 3 presents Mamcra algorithm proposed to solve multiple constraint multicast routing problem. This section emphasizes its weak points and proposes some improvements without great changes. Section 4 proposes a formulation of a new problem aiming to optimize the multicast sub-graph, the OMS problem. Section 5 investigates how the problem of optimizing multicast sub-graph must be tackled if incremental search algorithms are adopted and it proposes ICRA, an incremental algorithm to solve the OMS problem. Section 6 describes how the technique of taboo search can be used to provide a solution to the multiple constraint optimal multicast routing problem . Section 7 presents simulation results.

2 Multi-Constrained Routing Problems

In this section, we will give formal definition of multi-constrained QoS routing problems. We start by the unicast case since existing approach for multiple constraint multicast routing problem resolution is based on the unicast multi-constrained routing solution.

2.1 Unicast QoS routing

QoS routing problem or constraint-based routing consists of finding path from a source node to a destination that satisfies multiple QoS constraints. Since this field is quite mature, we give here a formal definition of the problem and we describe a sample of proposed solutions namely the Self Adaptive Multi-Constraint Routing Algorithm (Samcra) [22] since it is used as a basis for multicast QoS routing algorithm proposed next. Samples of abundant work can be found in [2, 3, 12, 15, 16, 14] and their references.

2.1.1 Unicast QoS Routing Problem Specification

A QoS routing solution involves two components: the routing protocol and the routing algorithm. The objective of the routing protocol is to manage available resources dynamicity. All nodes must have a realistic view of available resources and network utilization of all links. That's why the routing protocol defines the mechanism used to distribute this information called link state information. So, a link-state routing such as in OSPF [30] or PNNI [31] is mandatory to make every node share a map of the network topology and the available resources. Using this link-state information, the routing algorithm computes paths between a source node and a destination node that are within defined constraints or optimizes a certain criterion. The unicast routing algorithms attempt to solve the Multi-Constraint Path (MCP) Problem and/or the Multi-Constraint Optimal Path (MCOP) Problem. In the following, we will first specify some hypothesis used to solve these problems and then we will explain the notation used throughout this section.

Hypothesis 1: Proposed solutions assume that the network-state information (a set of link values) is temporarily static and has been distributed in the network and is accurately maintained at each node using QoS link-state routing protocols.

Hypothesis 2: The most frequently used QoS metrics are categorized into additive and min\max metrics (bottleneck or concave metrics). A QoS metric is additive (e.g., delay, jitter, the logarithm of the probability of successful transmission) when the weight (of that metric) of a path equals to the sum of the QoS weights of the links defining that path. In the case of bottleneck metrics, the weight of a QoS measure of a path is the minimum (maximum) of the QoS weights along the path (e.g., available bandwidth). Constraints on min (max) QoS measures can easily be treated by omitting all links (and possibly disconnected nodes) which do not satisfy the requested min (max) QoS constraints. In contrast, constraints on additive QoS measures cause more difficulties. Hence, without loss of generality, all QoS measures are assumed to be additive.

Hypothesis 3: The network topology is modeled as an undirected graph $G=(V,E)$, where V is the set of nodes and E is the set of links. Each link $(u,v)\in E$ is characterized by m additive QoS metrics. So we associate to the link an m-dimensional link weight vector of m non-negative QoS weights $\vec{w}(u,v) = [w_i(u,v), for i = 1,2,\dots,m]$. The m QoS constraints (which are the limits of the end-to-end values on the used paths) are represented by the constraint vector $\vec{L} = [L_1, L_2, ..., L_n]$.

Definition 1: Considering a path P of G composed of a set of links, the i^{th} weight w_i of P is defined as:

$$w_i(P) = \sum_{(u,v)\in P} w_i(u,v) \tag{1}$$

. We also define the weight of the path as

$$\vec{w}(P) = \sum_{(u,v)\in P} \vec{w}(u,v) \tag{2}$$

.

Multi-Constraint Path (MCP) problem In this case we consider the problem to find a path P from a source node s to a destination node d such that the QoS constraints are respected:

$$w_i(P) \leq L_i \text{ for } i = 1,2,\dots m \tag{3}$$

This kind of paths is called feasible path. They may be many feasible paths; it might be interesting to find, from the set of feasible paths, the path minimizing a cost function l(P), l

refers to a length function, it can be any function of the weights w_i provided it obeys to the criteria for length or distance in vector algebra. Such a path is the solution of the MCOP problem which can be defined formally as follows.

Multi-Constraint Optimal Path (MCOP) problem

In this second case, the problem is to find a path P^* from a source node s to a destination node d such that:

$$w_i(P^*) \leq L_i \textit{ for } i = 1,2,\ldots m \tag{4}$$

$$l(P*) \leq l(P) \ \forall \ P, \ P* \text{ satisfying (4) where } l \text{ is a length function} \tag{5}$$

To illustrate the MCOP problem, let's consider the case of finding multi-constrained paths where the cost function l is given by:

$$l(P) = \max_{1 \leq i \leq m} \frac{w_i(P)}{L_i} \tag{6}$$

Note that the solution (or the solutions when there are multiple shortest paths) of the MCOP is not necessary element of the Pareto optimal set [1]. It depends on the length function adopted to evaluate multi-constrained solutions. (Figure 1) illustrates the relation between the set of possible paths and feasible paths in the case of two additive metrics ($m = 2$). The paths are represented in the plan. Each point corresponds to a path represented by its vector $l_i = w_i / L_i$. So the feasible solutions are inside the square $L(1,1)$. In this case, when using the length function defined in (6), the optimal solutions of the MCOP problem are in the perimeter of the minimal length square (indicated with dotted line) which contains at most one element of the Pareto optimal set.

2.1.2 Unicast QoS routing problems resolution

The MCP and MCOP problems are NP-complete [7] and to solve them, heuristic algorithms are needed. [14] gives a survey of most proposed algorithms and compare them. The main idea used by most algorithms is to find out a length function which can be used to scan feasible solutions. So, the problem is simplified to a problem that is solvable by a shortest path algorithm such as Dijkstra or Bellman Ford algorithms [5, 4]. One of the most promising proposed algorithms is the Tunable Accuracy Multiple Constraints Routing Algorithm (Tamcra). To solve MCP problem, Tamcra [23] uses the non linear length combination weight given in (6).

The weight defined in (6), guarantees that P is feasible, if it verifies:

$$l(P) \leq 1 \tag{7}$$

In addition of the non linear weight, Tamcra uses the k-shortest path approach [1]. It is essentially a version of Dijkstra's algorithm that stores for each node more sub-paths

[1] the Pareto Optimal Set is the set of non dominated paths, knowing that a path P_1 is dominated by a path P_2, when $w_i(P_1) \leq w_i(P_2)$ for i=1,...,m